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The Effects of Elbow Joint Angle Changes on Elbow Flexor and Extensor Muscle Strength and Activation

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Abstract. [Purpose] This research investigated the relationship between elbow joint angle and elbow flexor and extensor strength and activation, taking into consideration the length-tension tension curve of the muscle. [Subjects] There were 30 research subjects in total, 15 male and 15 female college students from Busan S University who had no functional disabilities that might affect measurement of muscle strength and muscle activation, and none had they experienced any damage in their upper extremities or hands. [Methods] The elbow joint angles were positioned at angles of 56°, 70° and 84°, and then muscle strength and activation were compared. Repeated measures ANOVA was used for statistical analysis, and the paired t-test was used to identify the difference between each angle. We used the SPSS for windows (ver. 21.0) statistical software and a significance level of α=0.05. [Results] The results showed that muscle strength and activation of the biceps was highest when the joint was placed at 56°. On the other hand, for the triceps, the result was highest when the joint angle was placed at 84°. [Conclusion] The tests confirmed that muscle strength and activation were highest at the joint angle at which the muscle was stretched to 20% more than the resting position in concentric contraction.

Key words: Joint angle, Muscle strength, Muscle activation

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INTRODUCTION

Various movements are possible in the human body because many segments are connected by joints[1)]. Movement of the joints takes place by contraction of muscles around the joints[2)]. Then muscle tension occurs, and the total tension is known as muscle strength[3)].

Muscle strength is determined by the recruitment of a number of motor units[3)], and muscle activation represents the degree of activity of motor units[4)], so muscle strength is related to muscle activation[5)]. Since muscle strength is affected by the change in length of the muscle when it contracts, when we look at the length-tension curve of muscle, the largest amount of tension can be seen within a specific range of muscle lengths[6)]. The change in muscle length is closely related to the change in joint angle. Hence, the change in joint angle affects muscle contractive force and its function[7, 8)], and therefore joint angle can be a variable affecting the maximum force that is generated by the muscle[9–11)].

Most existing research has been about the relationship between maximum muscle strength and the change in muscle length, and the existing reports contain conflicting results. Gandevia and Mckenzie[12)] stated that muscle activation is always constant regardless of the muscle length. Meanwhile, Nicholas et al.[13)] stated that changes in muscle length affects muscle activation. An et al.[7)], Kim[14)], and Kim[15)] mentioned that the change in joint angle and muscle length can be a variable to muscle activation and contractive force.

Kasprisin and Grabiner[16)] stated that the shorter the muscle length, the higher the muscle activation, whereas Komi et al.[17)] stated that decreases in muscle length lower the muscle activation. Generally, considering the length-tension curve of muscle, it is known that changes in muscle length can affect muscle activation, but previous research has reported various results about the relation between muscle length and strength. Nevertheless, to minimize injuries when performing exercises for muscle strength in different position for the purposes of rehabilitation and health promotion and to enable performance of exercise comfortably[18)], it is vital to investigate optimal joint angle and muscle length. Since it is important to consider the exercise position or joint an-

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gle position that can accomplish the purpose of the exercise from the planning stage[19], it is necessary to investigate the optimal muscle length and joint angle for generation of the maximum muscle strength[20].

However, because the lengths of all muscles are different, it is difficult to objectify and generalize a standard muscle length and conditions that produce the maximum muscle strength. Hence, a research study regarding the relation between muscle angle (which is comparatively easier to objectify and generalize than muscle) and muscle strength was undertaken. Nam[21] measured the muscle strength at elbow flexion angle of 110 to 70 degree in 5-degree intervals, and Na[22] measured the muscle strength at hip joint angle of 90 to 160 degrees in his research.

But these studies are only applicable to particular joints, so they could not provide generalized standards for all joints. Considering the length-tension curve of muscle in particular, a scientific basis for the optimal joint angle that is objectively applicable to all the joints has not been provided. Therefore, the aim of this study was to find the best way to generalize all the joints, taking into consideration the length-tension curve of muscle.

SUBJECTS AND METHODS

The participants in the present study were 15 male and 15 female students attending S University in Busan, Republic of Korea. The average age of the male students was 24.0±1.0 years, their average height was 173.0±6.1 cm, and their average weight was 70.0±8.2 kg. The average age of the female students was 23.0±0.0 years, their average height was 159.0±5.4 cm, and their average weight was 54.0±5.3 kg. The purpose and methods of the research were fully explained to the participants before the experiment was carried out. This study complied with the ethical standards of the Declaration of Helsinki, and written informed consent was received from each participant. The participants were healthy students who had no functional disability with respect to measuring muscle strength and muscle activation, and none who had any experience of damage to an upper extremity or hand.

The elbow joint was selected to examine the relation between range of motion and muscle strength and activation. A Professional Goniometer Set (Patterson Medical, P.R. China) was used to measure the angles of the elbow joint of the participants. The line connecting the greater tuberosity of the humerus and lateral epicondyle was set as the fixed axis of the goniometer. The radial head of the forearm was set as the standard on the axis of rotation of the goniometer. The resting position of the shoulder was adduction of 55°, whereas the horizontal adduction was 30°. The resting position of the elbow joint was elbow flexion of 70° and supination of 10°. A Sthenometer (BIODEX System III, Biodex Medical System, Shirely, USA) was used to measure the muscle strength of the elbow during performance of isometric exercise. The subjects were asked to sit on the measuring chair, and the condyle of the humerus was adjusted to be perpendicular to the axis of rotation of the dynamometer. To avoid using other parts of the body, straps were used to immobilize the chest and the lower legs. Muscle strength and activity were measured at the angles of 56°, 70°, and 84°. After each fixed angle was set, flexion and extension were carried out alternately through isometric exercise, and the muscle strength was measured.

According to Son's[18] research, the maximum tension of the muscle is shown when the muscle length is more than 1.2 times longer than at the resting point. Hence, angles were selected that represented a 20% stretch compared with the resting position of the elbow joint. Flexion was performed with the biceps stretch 20% at an angle of 56°, and extension was performed with the triceps stretched 20% at an angle of 84°. Measurements were taken at 56°, 70°, and 84° accordingly. At each angle, the isometric strength of flexion was measured. After a 10-second break, the isometric strength of extension was measured. To prevent muscle fatigue, 3 minutes of rest was given after every measurement of an angle. Measurements were performed 3 times, and the average of the 3 measurements was used for analysis. To facilitate holding an accurate position while the movements were performed, two practice trials were carried out before proceeding with the main experiment. Measurements of muscle activation and muscle strength were carried out together.

While muscle strength was being measured, surface electromyography (Keypoint, Medtronic, Minneapolis, MN, USA) was used to measure the muscle activation of the biceps brachii and triceps brachii. A disposable surface electrode that was 1.2 cm to 2.5 cm long was used as the electrode, and a unipolar surface electrode with a diameter of 3 cm was used as the ground electrode. To decrease the effect of the resistance of the skin on the electromyogram signal, all hair at the electrode attachment site was removed, and rubbing alcohol was used to remove the skin oil before attaching the electrode. Next, a small amount of electrolyte jell was used to attach the electrode to skin. The electrodes were attached to the bellies of two muscles (biceps brachii muscle and triceps brachii muscle), and there was a 1 cm space between the two electrodes.

The EMG values collected were the root mean square of each muscle's RMS values for 4 seconds. The EMG value for only the last 3 seconds was used for analysis (thereby excluding the first second). Repeated measures ANOVA was used to check if there was any difference in muscle strength and muscle activation at the angles of 56°, 70°, and 84° in the statistical analysis. The paired t-test was used to evaluate the difference between angles. Statistical analysis was performed with SPSS for Windows (ver. 21), and the significance level was $\alpha=0.05$.

RESULTS

The results of examining the difference in elbow joint angle and elbow joint muscle strength are shown in Table 1. Regarding flexion of the elbow joint, the maximum torque value were 34.2 Nm at 56°, 32.4 Nm at 70°, and 31.4 Nm at 84°. The value was highest at 56°, but there was no statistical difference. On the other hand, after examining the differences between the angle, it was apparent that maximum

Table 1. The differences in muscle power according to angle (Unit: Nm)

Variables		56°	70°	84°
Maximum torque	Flexion	34.2±17.1[a]	32.4±14.6	31.4±14.4
	Extension*	26.8±9.9[b]	27.9±8.9[c]	29.8±9.8
Mean torque	Flexion*	31.4±16.0[d]	29.9±14.4	28.2±14.2
	Extension*	23.9±9.4[e]	24.1±8.3[f]	27.5±9.2

Mean±SD. *: Repeated measures ANOVA test ($p<0.05$).
By paired t-test: [a]56°>84° ($p<0.05$). [b]56°<84° ($p<0.05$). [c]70°<84° ($p<0.05$). [d]56°>84° ($p<0.05$). [e]56°<84° ($p<0.05$). [f]70°<84° ($p<0.05$).

Table 2. The differences in muscle activation according to angle (Unit: mV)

Variables		56°	70°	84°
Biceps activation	Flexion*	617.7±158.6[a,b]	555.5±156.9[c]	503.3±152.3
	Extension*	489.9±140.0[d,e]	455.6±150.7[f]	412.9±137.4
Triceps activation	Flexion*	370.0±162.4[g,h]	420.4±174.3[i]	489.9±191.0
	Extension*	422.6±192.7[j,k]	498.1±215.7[l]	599.3±234.5

Mean±SD. *: Repeated measures ANOVA test ($p<0.05$).
By paired t-test: [a]56°>70° ($p<0.05$). [b]56°>84° ($p<0.05$). [c]70°>84° ($p<0.05$). [d]56°>70° ($p<0.05$). [e]56°>84° ($p<0.05$). [f]70°>84° ($p<0.05$). [g]56°<70° ($p<0.05$). [h]56°<84° ($p<0.05$). [i]70°<84° ($p<0.05$). [j]56°<70° ($p<0.05$). [k]56°<84° ($p<0.05$). [l]70°<84° ($p<0.05$).

torque value at 56° was higher than at 84° ($p<0.05$). With extension of the elbow joint, the maximum torque values were 26.8 Nm at 56°, 27.9 Nm at 70°, and 29.8 Nm at 84°, demonstrating a difference at each angle ($p<0.05$). After examining the differences between the angle, it was found that the maximum torque value at 84° was higher than those at 56° ($p<0.05$) and 70° ($p<0.05$). With flexion of the elbow joint, the average torque value were 31.4 Nm at 56°, 29.9 Nm at 70° and 28.2 Nm at 84° ($p<0.05$). After examining the difference between the angles, it was found that the average torque at 56° was higher than that at 84° ($p<0.05$). With extension of the elbow joint, the average torque values were 23.9 Nm at 56°, 24.1 Nm at 70° and 27.5 Nm at 84°, demonstrating a difference at each angle ($p<0.05$). After examining the difference between the angle, it was found that the average torque at 84° was higher than those at 56° ($p<0.05$) and 70° ($p<0.05$).

The results of investigating the effect of elbow joint angle on muscle activation of the biceps and triceps are shown in Table 2. The muscle activation levels of the biceps at the different angles of flexion were 617.7 mV at 56°, 555.5 mV at 70°, and 503.3 mV at 84°, with significant differences being found at each angle ($p<0.05$). The results showed that muscle activation at 56° was greater than at 70° ($p<0.05$) and at 84° ($p<0.05$) and that muscle activation at 70° was greater than at 84° ($p<0.05$). Regarding extension, the muscle activation levels of the biceps were 489.9 mV at 56°, 455.6 mV at 70°, and 412.9 mV at 84°, with significant difference being found at each angle ($p<0.05$). The results showed that muscle activation at 56° was higher than at 70° ($p<0.05$) and at 84° ($p<0.05$), and that muscle activation at 70° ($p<0.05$) was higher than at 84° ($p<0.05$). The muscle activation of triceps showed that at flexion it was 370.0mV at 56°, 420.4mV at 70°, and 489.9mV at 84°, which showed a difference at each angle ($p<0.05$). The result of different angles showed that muscle activation at 84° was higher than at 70° ($p<0.05$) and at 56° ($p<0.05$), and muscle activation at 70° was higher than at 56° ($p<0.05$). At extension, the muscle activation levels of the triceps were 422.6 mV at 56°, 498.1 mV at 70°, and 599.3 mV at 84°, with significant differences being found at each angle ($p<0.05$). The results showed that muscle activation at 84° was higher than at 70° ($p<0.05$), and that at 56° ($p<0.05$), and muscle activation at 70° was higher than at 56° ($p<0.05$).

DISCUSSION

For each joint of the body, there exists an optimal advantageous joint angle[2)], and at that angle, the muscle will have an optimal length that can exert the maximum power[23)]. After all, muscle strength is determined by the length-tension relationship of the muscle and the mechanical qualities of a lever. So it is important to know the relationship between muscle strength and joint angle in order to carry out more effective muscle strength improving exercise[24)].

In connection with this, Lee[25)] stated that when carrying out a movement, if the optimal muscle length and joint position are fixed at the appropriate place, the maximum power can be generated comfortably, and the exercise can be performed more effectively. In other words, because muscle strength is affected by the joint angle, exercise should be performed at an angle at which the maximum muscle contraction can take place to exert the largest force. However, the fact is that up to now there has not been a scientific basis for the optimal joint angle that is objectively applicable to all the joints.

Borstad[26)] stated that generally a movement takes place at the resting position when the resting length of the muscle related to the movement is shortened. So to find out the optimal joint angle, it is appropriate to set the joint angle of the

resting position as the standard. Cooke and Fay[27] explained that although the active force of a muscle is highest a muscle's resting length, when the muscle length is stretched 20–30% beyond the resting length, the passive force increases, and the total force also becomes greater. Hence, in this research, we chose to examine the relationship between joint angles at which the muscle was stretched to 20% more than the resting position and muscle strength in order to provide a scientific basis that is applicable to all the joints. First, when selecting the joint angle of the elbow, the resting position and muscle length-tension relationship were used to select 3 kind of joint angles. The angles of 56° and 84° were selected because these two angles represented the angles at which the agonist biceps and triceps were stretched 20% during concentric and eccentric contraction and were the angles at which the maximum muscle strength was seen. The results of the present study showed that muscle strength and muscle activation of the biceps were highest at the joint angle of 56°, whereas for the triceps, the highest muscle strength and muscle activation were found at the joint angle of 84°. The results confirmed that muscle strength and muscle activation were highest at the joint angle where concentric contraction was 20% more stretched than in the resting point. This result is very similar to the results of other research. Nam[21] measured muscle strength with elbow joint flexion angles of 110° to 70° in 5-degree intervals, and the results showed that the smaller the elbow joint flexion angle, the higher the rate of increase of muscle strength. So at a joint angle of 70°, the rate of increase of muscle strength was the highest. The results for muscle activation at biceps joint angles of 70° and 80° also agreed with those in the present research, which showed that thee muscle activation at 70° was higher than that at 84°. However, in Nam's[21] research, the angle at which muscle length was 20% stretched in relation to the resting point of the joint was not considered. So Nam's[21] research data cannot be generalized to all joints, whereas the advantage of the present research is that it is applicable to all the other joints.

As a result, the present research demonstrated that the total force at a joint angle stretched 20% is greater than the total of the active force and passive force exerted in the resting position. Hence, regarding muscle-strength improving exercises, applying the maximum resistance at a joint angle representing 20% muscle stretch in a more significant factor for improving muscle strength than applying it at a joint angle representing a resting position. Nevertheless, this research was only performed with respect to the change in length-tension curve of the elbow joint, so it is not easy to broaden the interpretation to all joints. Therefore, in the future, we are considering performing research using the same method on other joints by examining the muscle strength and muscle activation with a joint angle representing 20% stretch from the resting position.

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